USFWS Anadromous Fish Restoration Program
CALFED Bay-Delta Program

MERCED RIVER
ADAPTIVE MANAGEMENT FORUM REPORT

Prepared by the

Adaptive Management Forum Scientific and Technical Panel

with assistance from the
Information Center for the Environment
Department of Environmental Science and Policy
University of California, Davis

This project was made possible with funding from
the Central Valley Project Improvement Act Anadromous Fish Restoration Program
with assistance from
the CALFED Bay-Delta Program, Ecosystem Restoration Program

July 19, 2002

TABLE OF CONTENTS

MERCED RIVER ADAPTIVE MANAGEMENT FORUM
SCIENTIFIC AND TECHNICAL PANEL

Robert E. Bilby, Ph.D.
Senior Scientist, Weyerhaeuser Company

Thomas Dunne, Ph.D.
Professor, Donald Bren School of Environmental Science and Management
University of California, Santa Barbara

Michael C. Healey, Ph.D.
Professor, Institute for Resources and Environment and
Department of Earth and Ocean Sciences
University of British Columbia

Robert A. Mussetter, Ph.D., P.E.
Principal Engineer, Mussetter Engineering, Inc.
Fort Collins, Colorado

Patrick L. Redmond, M.S., P.E.
Civil/Geotechnical Engineer and Principal, Piedmont Engineering, Inc.
Belgrade, Montana

Michael L. Scott, Ph.D.
Ecologist, Stream and Riparian Ecology Section,
U.S. Geological Survey, Fort Collins Science Center

With

Carrie A. Shaw, M.S.
Environmental Science and Policy Analyst, Information Center for the Environment
University of California, Davis

1. EXECUTIVE SUMMARY

To ensure maximum benefits from the many millions of dollars that they spend on ecological restoration in the Sacramento and San Joaquin river watersheds, the U.S. Fish and Wildlife Service's Anadromous Fish Restoration Program (AFRP) and the California-Federal Bay-Delta Program (CALFED) have required that adaptive management be incorporated into the planning, design, and implementation of the restoration projects they help fund. The Adaptive Management Forum (Forum) was initiated to review current restoration project designs and offer recommendations on how to make adaptive management a more comprehensive and active component of the projects. For two days in late November 2001 the Forum's panel of scientific and technical experts (Panel) met with the Merced River Restoration Team (restoration team) and reviewed the design and implementation of some of the channel and floodplain habitat restoration projects on the lower Merced River. This report summarizes the comments and recommendations of the Panel and are grouped into five topic areas: Ecosystem Perspective; Project Design and Implementation; Monitoring; Opportunities for Experiments; and Coordination of Projects, Investigations, and Experiments on the Merced and Tuolumne Rivers.

The channel and floodplain habitat restoration projects on the Merced River provide an exciting opportunity to apply ecosystem-based management to the recovery of listed species. The projects are based on a strong, attractive conceptual design that relates the restoration of both channel and floodplain habitats for a multitude of plants and animals to the establishment of a mobile channel. The channel geometry is scaled so that sediment transport and channel modification will occur in floods of moderate frequency (two-to-five year recurrence frequency) under a modern flow regime that is severely reduced by dams and diversions. Other innovations such as building in to the channel a certain amount of pool and riffle habitat, bends that are expected to foster bank erosion and bar building, and a small amount of floodplain microtopography, also constitute a novel approach in central California, and thus the project introduces an important degree of innovation to river restoration in the region.

Although each reach-scale restoration project on the Merced River is being carried out in a creative manner, it was not always obvious to the Panel how the projects for the separate reaches fit into an overall ecosystem-based design. Were the reaches expected to serve complementary ecological functions? How were the various components of the projects within each reach (e.g., channel reconstruction, floodplain creation, riparian revegetation) integrated? The scientific foundation of the riparian revegetation, in particular, could be developed further, both to increase the probability of success and to provide information that could be transferred to other central California rivers.

The design and construction of the restoration projects on the Merced River were well organized and carried out. It appeared, however, that there were still some problems in translating ecological design into engineered structures. There may be a need to review the way in which scientists and engineers collaborate in the design and implementation of these large-scale channel and floodplain restoration projects to further reduce these kinds of problems.

Choosing the proper restoration model is important. Reference reaches can provide a model in some instances, but in highly altered systems such as the Merced River an approach based on first principles is more likely to yield results. The Panel compliments the restoration team for taking this design approach. Working from first principles does, however, introduce additional uncertainty into the outcome. These uncertainties need to be more fully explored with quantitative modeling and experiments to evaluate whether some of the features should be worked into the project designs. Of particular concern were the highly uniform channel morphology and floodplain elevation of the Robinson Reach project. Such uniformity ignores many biologically important aspects of channel complexity and floodplain topography. Additional complexity could have been included in the design that would have provided important opportunities for experimentation and learning.

Riparian revegetation was one of the weakest aspects of the restoration design. Of particular concern is the probability that non-native weedy species might quickly colonize the large open expanse of reconstructed floodplain at the Robinson Reach project and prevent the establishment of native species. There is a need to evaluate strategies that discourage establishment of non-native weedy species, which typically preempt the passive establishment of desirable native species.

The monitoring program for the Merced River was deficient in a number of respects. Pre- and post-project monitoring and analysis are critical aspects of adaptive management. In many instances, existing information that was critical to project design had not been assembled and analyzed to ensure that design was appropriate and that quantitative expectations were established. Tools such as physical and biological modeling were not used to explore the potential response of the river ecosystem to restoration and to identify gaps in knowledge and understanding that should be addressed. Plans for post-project monitoring were weak or poorly designed, reflecting the lack of conceptual models and quantitative expectations for the restoration project. Furthermore, monitoring was poorly and inappropriately staffed and funded. Without a much stronger commitment to effective project monitoring, even passive adaptive management cannot be realized.

The greatest benefit from the restoration effort on the Merced River can only be realized if the many opportunities for active experimentation are incorporated into the design of current and future projects. The Panel outlines some experiments concerning fluvial morphology, salmon spawning and rearing, and riparian revegetation. There are, however, many other experimental opportunities inherent in the restoration projects along the Merced River. The most important experiments should be identified by the (as yet undefined) overarching conceptual model of restoration and by integration of the conceptual models for the individual reaches.

Beyond the obvious opportunities to test hypotheses about large-scale channel and floodplain restoration, the Merced River restoration also provides a unique opportunity to gather basic information on many poorly understood species of concern. The Panel was struck by how little information was presented on species other than chinook salmon and even for salmon there were significant gaps in understanding. Without better information on the natural history of the species to be restored, the Panel doubts that restoration can be designed with sufficient confidence to justify the cost. Gathering the necessary basic information on all species of concern should be given a very high priority.

Restoration of fall-run chinook salmon is a key focus of the restoration of the lower Merced River. The underlying assumption is that restoration of natural fluvial and floodplain dynamics is the key to salmon restoration. The Panel cautions that water quality, in particular trace concentrations of certain contaminants, may also be important to salmon viability. Furthermore, the strongest factor linked to salmon survival is low flows. The mechanisms underlying this relationship should be a high priority for investigation.

The channel and floodplain restoration of the Merced River has many similarities to the proposed restoration of the Tuolumne River. Both restoration efforts would benefit from stronger communication and coordination. The opportunities for effective experimentation will be multiplied if the projects can be developed in complementary ways. Although a small amount of communication is occurring between the restoration teams, neither the AFRP nor CALFED (the agencies with overall responsibilities for funding and coordination) seem to be insisting on increased collaboration. Consequently, unique opportunities for cooperative and complementary restoration projects and experimentation on the Merced and Tuolumne rivers are being lost.

To capitalize on the opportunities presented by the large-scale restoration projects on the Merced River, a team with the proper training and experience in investigating river ecology and fluvial dynamics should be assembled, tasked, and adequately funded to undertake the necessary studies and monitoring in the project reaches. This team should be mobilized without delay because the first few high flow events following the channel and floodplain restoration are likely to provide the most important indications of how the system will behave. This team might also provide a vehicle for coordinating and integrating information gathering and sharing among multiple large-scale restoration projects. This investigative team might also coordinate, disseminate, and integrate information gathered from multiple large-scale restoration projects.

In conclusion, the channel and floodplain restoration projects on the Merced River are well designed and executed in terms of restoring a simple channel design to meet broadly specified ecological objectives. Each individual project is being executed well. The restoration program, however, is weak in terms of an overall conceptual model for ecosystem restoration, in design for riparian habitat restoration, in project monitoring and evaluation, and a number of other areas critical to ecosystem-based restoration and adaptive management. The Panel's recommendations are directed at strengthening these shortcomings and enhancing the amount to be learned from the exciting restoration program on the Merced River.

2. BACKGROUND

The U.S. Fish and Wildlife Service's Anadromous Fish Restoration Program (AFRP) and the California-Federal Bay-Delta Program (CALFED) have contributed millions of dollars to the design and implementation of large-scale river channel and floodplain habitat restoration projects in the Sacramento and San Joaquin River watersheds. Because the field of river restoration is still largely experimental it is important to learn as much as possible from individual restoration efforts. To increase the information gained from these projects, both the AFRP and CALFED have required the project proponents use adaptive management in planning, design, and implementation (CALFED, 2001). So far this process has produced mixed results.

CALFED and AFRP anticipate the following benefits from an adaptive management approach:

- Those involved in river restoration will be able to update the models and methods used in river restoration on the basis of sound, scientifically credible information and subsequent projects can then be revised or redesigned to be more effective;

- Success and failure in restoration projects will be ascribed to specific causes, thereby reducing uncertainty in future projects;

- The credibility of multi-million dollar river restoration efforts will increase as will support from project stakeholders and the public; and

- An objective process for incorporating new knowledge (from carefully designed and monitored projects) into future project design and implementation will emerge.

The AFRP, assisted by CALFED's Ecosystem Restoration Program and the Information Center for the Environment (ICE) at U.C. Davis, have initiated the Adaptive Management Forum (Forum) to advise on the incorporation of adaptive management into project design and implementation.

2.1 FORUM GOALS AND OBJECTIVES

The goal of the Forum is to assist the AFRP and CALFED achieve maximum benefits in terms of ecological restoration and improved restoration technology by helping river restoration teams and program staff plan, design, implement, and monitor large-scale river restoration efforts using an adaptive management approach.

The Forum provides assistance to river restoration teams, their consultants, and restoration program staff by

- Reviewing conceptual models and habitat restoration plans,
- Helping to integrate multiple restoration projects, and
- Providing input and recommendations on project design, implementation, and monitoring within an adaptive management framework at a watershed scale.

Eventually, the Forum will also compare similar channel and floodplain restoration projects in different watersheds and recommend design, implementation, and monitoring strategies to address key uncertainties associated with these type of large-scale riverine habitat restoration efforts.

2.2 ADAPTIVE MANAGEMENT

Adaptive management is an analytical process that can be either passive or active (Walters 1986).

2.2.1 Passive Adaptive Management

Passive adaptive management involves the following actions:

a. Think of plausible solutions to management problems,
b. Subject the solutions to some form of structured analysis to determine which offers the greatest promise of success;
c. Specify criteria (e.g., indicators, measures) of success or failure of the most promising option;
d. Implement the option (with careful attention to the feasibility of discriminating cause and effect as the system changes) and monitor the system response according to the criteria of success and failure; and
e. Adjust the design of the solution from time to time according to the results of monitoring in an attempt to make the approach work better.

2.2.2 Active Adaptive Management

Active adaptive management involves the following actions:

a. Think of plausible solutions to management problems;
b. Subject these solutions to some form of structured analysis to determine the probable responses of the system and how uncertainty about system response effects the likelihood of success or failure;
c. Where uncertainty in system response makes it difficult to choose among solutions, design the management intervention so as to test among two or more alternatives;
d. Use monitoring data to reevaluate the alternatives and improve understanding of system behavior and optimal management.

2.3 THE STRUCTURE AND PROCESS OF THE FORUM

The Forum provides a structured way for river restoration teams and staff from the AFRP and CALFED to interact with an independent scientific and technical panel (Panel) that reviews the restoration projects and provides recommendations on the different phases of conceptual modeling, restoration planning, project design, implementation, and monitoring. The Panel, drawn from academia and the private sector, consists of experts in adaptive management, fish biology, fluvial geomorphology, aquatic invertebrates, aquatic ecology, riparian vegetation ecology, and civil and hydraulic engineering.

Each Forum session is three days long and covers one large-scale riverine restoration effort. The first three rivers being addressed by the Forum in 2001-2002 are the Tuolumne and Merced rivers, and Lower Clear Creek in Shasta County.

The first day of each Forum session is spent touring the rivers and visiting project sites. The second day consists of presentations and discussions among the restoration teams and consultants, the Panel members, and staff from the AFRP and CALFED. On day three the Panel members discuss the projects, develop preliminary recommendations, and outline their report.

3. INTRODUCTION

The current channel and floodplain restoration on the Merced River consists of several projects in various stages of development. The collective goal of the projects is to reverse the degradation of aquatic and riparian functions from decades of dredging for gold, gravel mining in the channel and floodplain, and the impoundment and diversion of water.

The four projects reviewed by the Merced River Adaptive Management Forum were:

- *The Ratzlaff Reach Project.* This project involved re-channeling the river around a large floodplain pond, as well as recontouring and revegetating a small area of floodplain to accommodate the reservoir-modulated two-to-three year flood as a bankfull discharge. This project had been completed at the time of the field tour.

- *The Robinson Reach Project.* This project included removing dikes, reconstructing the wide floodplain by redistributing terrace materials, and constructing a new single-thread channel, scaled to the two-to-three year flood. The project was in the final stages of floodplain shaping at the time of the field tour, but the floodplain had not been planted.

- *The Western Stones Reach Project (proposed).* This project will deal with a highly constrained section of the river, in which the channel appears to be incising and has encountered a clay hardpan of uncertain resistance, above which a knick point appears to be migrating upstream through the reach. A plan is currently being explored to emplace at least a narrow floodplain, but the conceptualization is in a very early stage.

- *The Dredger Tailings Reach Project (proposed).* In this reach large mounds of overturned floodplain gravels constrain the channel to a narrow, trough-like cross section and the floodplain has only a sparse cover of woody plants. This project is also at the exploratory stage of considering what the options are for restoration.

The Ratzlaff and Robinson projects, given the uncertainty in predictions of sediment transport and channel behavior, are essentially experiments (albeit not replicated). They will need to be monitored thoroughly to understand their evolution over the coming decades. They also constitute an important resource for developing quantitative information that can be transferred to other managed river channels in the region.

The design principles for each of the above projects are to:

- Create space for the river channel to migrate across the floodplain (usually by creating or reconstructing a floodplain),
- Rescale a single-thread channel to accommodate the two-to-three year flood (approximately),
- Adjust the texture of gravel on the bed so that it will favor Chinook salmon spawning and be mobile at flows near bankfull,
- Create at least a small amount of pool and off-channel habitat for juvenile anadromous fish rearing and other aquatic animals, and
- Re-vegetate the floodplain with native woody species and create enough micro-topography on it to provide a diversity of drainage conditions and various habitat conditions for a variety of preferred aquatic and terrestrial species.

It is intended that after construction the channel-floodplain system will be so close to natural functioning that it will require little engineering intervention to sustain it as productive habitat.

The Ratzlaff and Robinson projects provide excellent opportunities for incorporating both passive and active adaptive management. The two projects were designed using a carefully considered conceptual model of the behavior of fluvial systems and the biological consequences thereof. They were well constructed, and the physical aspects of the projects were well documented so that the initial physical state was defined. The Ratzlaff and Robinson projects are also valuable because they are a good size for conducting detailed studies with sufficient resolution to pin down quantitative answers about processes and to provide useful information for other projects.

The long-term value of these reconstructed reaches for improving the understanding of river restoration will be determined by a number of factors that include:

- The rate of channel and floodplain evolution within a reasonable time frame for conducting studies;

- The speed with which the initial biological state can be quantified, and
- The thoroughness and skill with which the continuing investigations of the consequences of the restoration design can be carried out.

The Panel sees a tremendous opportunity (subject to the above caveats) in studying these ambitious and well-executed projects as a way to improve the design criteria for future projects. The recommendations that follow are offered to help realize this opportunity.

4. RECOMMENDATIONS

The Panel's recommendations on the projects above are grouped into five areas:

- Ecosystem Perspective
- Project Design and Implementation
- Monitoring
- Opportunities for Experiments
- Coordination of Projects, Investigations, and Experiments on the Merced and Tuolumne Rivers

Most of the following recommendations refer specifically to the restoration projects and are directed toward the restoration team. A few of the recommendations are broader in scale and are directed toward program staff and managers for the principle funding agencies (i.e., the AFRP and CALFED).

4.1 ECOSYSTEM PERSPECTIVE

The restoration projects on the Merced River provide an exciting opportunity to apply ecosystem-based management to the recovery of listed species. However, it was not always obvious to the Panel how the individual projects fit into an overall ecosystem-based design. Fundamental to the ecosystem approach is a set of overarching objectives within which ecological restoration is situated and to which individual projects can easily be related. In the absence of such a framework, the Panel found it difficult to appreciate the interrelationships among the projects. Specific examples of this difficulty and suggestions for clarification are described below.

Ecosystem-based projects are also characterized by a nested design, with projects at the reach scale nested within the overall objectives for the tributary, and projects at particular sites nested within the objectives for the reach. Such nesting creates an inter-connectedness among projects that is critical to the overall effectiveness of restoration. This nesting of projects was not apparent to the review team.

4.1.1 Develop conceptual models for the Merced River that integrate the projects for the separate reaches and also integrate projects within reaches.

Restoration projects are planned for three very different reaches of the Merced River: the dredger tailings reach, the gravel mining reach and the encroached (sand-bedded) reach. Although conceptual models were provided for each reach and for the projects within reaches, there was no overall conceptual model that illustrated the relationship between the reaches in terms of ecological function and ecological restoration. Consequently, the Panel could not easily evaluate the gravel mining reach restoration projects (Ratzlaff and Robinson) in relation to proposals for the dredger tailings reach and the encroached reach. Ideally, the projects within each reach should form part of a nested design that supports the overall restoration objectives for the channel and floodplain.

In addition to these larger-scale relationships, there is a need to consider the relationship between components of the individual projects and how they will complement or possibly conflict with one another. For example, the relationship between floodplain restoration and river channel restoration needs to be considered. Is floodplain restoration intended primarily to complement river channel restoration? If this is the case, then revegetation might focus on anticipated need for channel shading, optimal bank stabilization, provision of organic detritus and large woody debris to the channel, etc. If floodplain restoration is intended to provide habitat for terrestrial and avian species as well, then other considerations come into play that may not be optimal in terms of stream channel maintenance. The Panel was told that an important objective of the riparian revegetation was to create "natural communities.” There are many possible natural communities, however, with different values to the stream channel and to listed species. The revegetation design needs to be much more carefully thought out.

4.1.2 Develop quantifiable objectives for the biological attributes of the ecosystem at the project (reach) scale and tributary scale.

Even at the project level, the expected biological response was often only expressed in a general manner, such as the re-establishment of “natural communities.” Because the primary goal of restoration on the Merced River is to restore the natural ecological conditions in the river channel and floodplain, some quantitative expression of the biological objectives at the project (reach) level and how that response would contribute to quantifiable objectives for the tributary should be developed. Some examples might be: providing high-quality spawning habitat for x- pairs of chinook salmon and nursery habitat for x-million juveniles; improving fry survival by x-percent; or reaching specific measures of cover, density, dominance, or species richness and diversity measures on the re-vegetated floodplains. These objectives can be developed by identifying the key physical-biological interactions anticipated in the conceptual models and by designing monitoring approaches that enable the quantification of these processes.

4.1.3 Establish clear short-term and long-term criteria for evaluating the success and/or failure of the restoration projects.

Clear objectives need to be developed for both the physical (structural) response of the channel and floodplain as well as the expected biological consequences. The restoration team needs to determine what results will signal that the restoration is being successful or is failing. An important goal, of course, is recovery of listed species. But this is such a long-term goal that it may not provide guidance rapidly enough to enable modifications in the monitoring program or aid in design of future restoration projects. Short-term indicators of success/failure are also needed.

The necessary indicators are of two types, structural and functional. Structural indicators would include such measures as streambed mobility under design flows, discharge necessary to inundate the floodplain, channel migration, survival and growth of riparian vegetation, etc. Functional indicators would include such measures as presence of listed and other native species, foraging success, and growth, survival, and reproduction. The choice of indicators will depend on the specific goals of different restoration projects.

Choosing appropriate indicators is important but not sufficient in itself. The restoration team must also identify how they expect the indicators to respond to restoration and the kinds of quantitative responses that will signal success or failure. These specific numerical targets then provide a set of benchmarks against which the performance of the restoration can be assessed objectively. It is important to note that, in the context of restoration, defining what constitutes failure is intended to give a clear indication of when it will be necessary to consider other restoration actions. It is not intended as a means to assess blame.

Finally, indicators should not only show the state of the system but also provide guidance on the kinds of remedial actions that would be most appropriate if the system is not responding as expected.

4.1.4 Gather information on other sensitive species and evaluate how the channel and floodplain reconstruction and revegetation designs will affect them.

The restoration team is obviously concerned and motivated to address a range of conservation issues. The Panel felt, however, that they had not made the best use of available information on additional species of concern. It is essential in any restoration effort utilizing adaptive management that restoration is built on a foundation of scientific information. The river channel restoration design had the firmest scientific foundation but the choice of the model of channel morphology and dynamics seemed as much an act of faith as an act based on investigations of the sites and their particular hydraulics and sediment transport characteristics.

There seemed to be little consideration of the importance of other determinants of fluvial morphology, such as hydraulic control structures, variations in channel width, etc., and their relationship to fish habitat let alone other aquatic species. The riparian revegetation designs seemed focused on establishing as many woody plants in the least amount of time with little connection to ecological principles or consideration of other species. There was no indication of how the riparian revegetation designs for the Ratzlaff and Robinson projects were expected to contribute to the function of the river and floodplain ecosystems, nor was there a monitoring plan that would shed some light on these fundamentally important aspects of the projects. A clear definition of the problems to be addressed, and the scientific understanding of the problems, is needed.

4.2 PROJECT DESIGN AND IMPLEMENTATION

In general, the channel and floodplain restoration projects on the Merced River appeared more structured and well organized than those that the Panel reviewed on the Tuolumne River.

As discussed in the Tuolumne River Adaptive Management Forum Report, an important step in stream restoration projects is translating the conceptual design, into plans and specifications that can be constructed within the available budget and still achieve the ecological objectives. There are two design/construction models that are typically used for large reclamation projects: the design-bid-build process and the design-build process. In the first, a project is designed and bid documents created that allow contractors to submit competitive bids to construct the project. The construction phase under this model is very rigid. Trying to incorporate design changes or additional work under this model often results in added time and costs and can generate friction among everyone involved.

The design-build process allows a construction company both to design and build the project. This process allows the contractor considerable latitude during the construction phase. The design-build model handles changes and fine-tuning of design features more readily because the designers and the contractor are operating as one entity. However, it puts considerable pressure on the scientists and other stakeholders to fine-tune their goals and objectives prior to the design. This model can save on project cost if agreement on the desired finished product can be determined prior to, or during the initial stages of design.

The following recommendations highlight improvement to the current design-bid-build process on the Merced River.

4.2.1 Improve the linkages between scientific input, project design (including engineering), and construction.

Scientific input is critical prior to project design and during the initial and active stages of the design. This input establishes critical objectives for the designer, guides the project to achieve the stated objectives, and ensures quantitative post-construction monitoring to determine if the objectives have been met. This process did not seem to be in place for the projects the Panel reviewed on the Merced River.

Involvement of scientists is required throughout the design and construction process. However, during the latter stages of the design, and particularly during construction, the input should be limited and should be directed toward interpretation of the design documents. Changes in the design concept at the latter stages of a project should be discouraged since this affects both scheduling and cost. If there is significant doubt at this stage as to the expected project outcome or scientific basis for the project, then it is probably being prematurely implemented or should only be implemented in an active adaptive design. For example, the revegetation plan for the Robinson Reach was in the process of implementation but there appeared still to be considerable debate over the best method of accomplishing this revegetation. In addition, the specific objectives of the revegetation design were not well defined.

The preparation of solid bid documents forces critical thought. The contractor only builds the design according to the bid documents at the time of issue. Items that are nebulous and cannot be depicted properly on design drawings can be bid on a “time and materials” basis to allow direct supervision by engineers or scientists. “Time and materials” bidding can also be used to experiment with design variations within the project. Streambank complexity or channel bottom contouring are excellent examples of items that are commonly bid this way. It was not clear that the restoration team took advantage of this option.

4.2.2 Consider other paradigms for project conceptual designs.

Mistakes are often made at he conceptual design stage because an inappropriate paradigm has been used. Commonly used reference models include the "reference reach," empirical relationships between flow and channel geometry, and "historic condition." Each of these reference models can lead to flawed design. An implicit assumption in use of a reference reach is that the reach has adjusted to the water and sediment supplied to it (Wilcock, 1997). It is rarely, if ever, possible to find a stable stream reach that has adjusted to the same water and sediment input as will be delivered to the repaired stream after the project is complete. Other factors can also exert significant control on the behavior of the stream, including geologic and man-made controls, bed armoring, and vegetation growth. These factors are often difficult to match between the “reference” reach and the reach that is to be rehabilitated.

The use of empirical relationships for designing channel geometry is also problematic. Although the relationships may describe conditions at the location where the data were collected very well, these rarely match conditions at the reach that is being repaired.

Although historical information on a stream can serve a variety of uses, the pre-disturbance character of the stream is unlikely to provide a sound basis for designing the repairs, especially when flows and sediment supply are greatly altered. Unless the historical water and sediment supply are restored, the historical channel characteristics are an inappropriate basis for the design.

A more useful model for the restoration design is that the stream will adjust to the water and sediment supply, subject to the other physical controls. By using available analytical tools to evaluate the hydraulic and sediment transport conditions over the range of expected future flows, the designers are more likely to arrive at a design that will respond to future flows in the expected manner, thereby increasing the odds that project objectives will be met. Although the Merced River projects show more use of an analytical approach than the Tuolumne River projects, the Panel was presented with little evidence that state-of-the-art analyses of flow, sediment transport, and channel mechanics had been used to design either the projects or the monitoring scheme.

4.2.3 Prioritize the project objectives.

There seemed to be no direct link between the design objectives for the channel and floodplain projects on the Merced River and expected performance. There were generalized objectives, however, they were not prioritized according to the weight each carried toward improving chinook salmon habitat or riparian habitat restoration. Which is most important? Should an extra mile of stream channel be reconstructed or should riparian vegetation be restored that extends well beyond the confines of the constructed channel? The designers could not give a clear answer when the Panel members asked what the priority would be if a choice had to be made on how to spend the available funding. It is apparent that in an effort to accommodate all parties there is a reluctance to define one objective as more important than another. However difficult it may be, such prioritization is critical to efficient project design and successful restoration.

4.2.4 Establish performance criteria and develop a process to evaluate project success (including figuring out what happened if things go wrong).

The linkage between the project objectives and the monitoring plans for the physical and ecological attributes at each project site need to be strengthened considerably. The objectives for the Robinson Reach, for example, include increasing the quantity and quality of spawning and rearing habitat, improving river and floodplain dynamics, and creating and enhancing the riparian corridor. Each of these objectives needs to be tied to one or more specific physical attributes of the reach. The physical monitoring plan for the Robinson Reach describes a variety of measurements that will be made, but it is unclear how these measurements will be directly linked to the project objectives. A series of quantitative performance criteria should be established for each objective based on the physical parameters that are to be measured. Any measurements can then be compared to the quantitative criteria to evaluate whether or not the project objectives are being met. For example, the criteria for bed mobilization might be that the surface material at the spawning areas would mobilize at least once every year. A series of particles within these areas could be marked and observed after each flow event to determine whether or not mobilization occurred. If a substantial percentage of the marked particles did not move within the specified time frame, it would be concluded that the performance criteria are not being met. Comparison of the characteristics of the areas where the criteria were met with those where they are not would provide valuable information on design strategies that have a high chance for success.

4.2.5 Consider opportunities to manipulate the Robinson Reach project channel and floodplain engineering design and revegetation design.

There are opportunities to use portions of the Robinson Reach project for a manipulative experiment to examine an alternative engineering and revegetation design that involves creating a topographically diverse floodplain surface.

Engineering

It is generally agreed that the complexity inherent in natural stream systems is important to the health of the in-stream and riparian organisms (FISRWG, 1998). A balance must be found between the scientist's desire for complexity, and the construction problems and high costs that can arise in attempting to build to that level of complexity. In many cases, budgetary constraints result in a project design that is overly simplified, or does not include project features that will ultimately be important to the proper functioning of the repaired system.

An example is the floodplain design in the Robinson reach. It was designed and constructed with little or no topographic diversity in order to conserve materials and to facilitate construction. Future overbank flows might cause scour and deposition that will ultimately result in the appropriate diversity. It is, perhaps, equally likely that future overbank flows will cause the constructed channel to avulse, resulting in strong alteration of certain aspects of the project, and perhaps even threats to restoration plans for adjacent reaches. In addition, the lack of topographic diversity may also prevent establishment of an appropriate distribution of floodplain vegetation, which may further jeopardize the success of the project.

Another example is the design for the river channel in the Robinson reach. Relatively simple cross sectional shapes were used in the design, with a symmetrical, trapezoidal shape for the riffle cross-sections and an asymmetrical, trapezoidal shape for the pool sections on the outsides of the bends. Although natural riffles tend to have relatively symmetrical shapes and pools that occur on the outside of bends tend to be asymmetrical, the design used for this project is much simpler than the typical natural shape. As a result, important channel features may not be present. For example, the lower approximately 1/3 of the banks along the straight, riffle sections have a 2H:1V slope and the slope of the upper 2/3 of the banks is about 10H:1V. Similarly, the banks on the outside of the bends in the pool sections have a slope of 2H:1V. In natural systems, the banks in these locations are often much steeper (particularly on the outsides of the bends) and are often undercut. These are characteristics that are considered important to instream habitat. In addition, the channel bottom in the pool sections is relatively wide and flat. Because the channel boundary material, including the banks, are constructed of non-cohesive gravel and cobbles, it would not be possible to construct vertical or undercut banks such as those that typically occur along natural streams. The river may eventually form more vertical and undercut banks, and the pools may deepen on the outsides of the bends as the vegetation becomes more established and channel erosion occurs during future high flows. Given the granular nature of the bank material, however, it is equally (or perhaps more) likely that the banks will simply erode laterally causing the channel to migrate rapidly across the floodplain or to excessively widen. While these processes are natural and important to maintaining a functioning stream, the rate of change during the high flows that occur in the next several years may be unacceptable.

In designing projects of this type, a balance must be found between the ultimate complexity that is necessary to achieve proper ecosystem function and the simplicity that is necessary to allow the project to be constructed within the available time and budget. The reasons for the design concept that was used in the Robinson reach are certainly understandable from a cost and constructability viewpoint, but the risk of failure may be high due to uncertainty in how the channel will respond to future high flows. The argument that a simpler design is good because the channel will eventually adjust to its “desired” state is very attractive, but the degree to which that adjustment will actually occur depends on many factors, some of which are not within the control of the project designers. Given the uncertainty in how the channel will respond to high flows, some experimentation with different channel designs would be advantageous. It is probably not too late to introduce some modifications that would allow the project team to test some modest hypotheses about channel evolution but these would have to be designed and implemented quickly.

Riparian Revegetation

The current design calls for actively revegetating a graded floodplain surface, which is flat and relatively featureless. However, by mimicking the natural variability in floodplain topography in a number of replicated plots, and comparing these against plots on the existing, level floodplain surface, it would be possible to quantitatively evaluate the hypothesis that topographic diversity of the floodplain increases plant species diversity.

The distinctive fluvial geomorphic processes and hydrologic conditions found on floodplains typically structure riparian vegetation. Infrequent, high-power floods create disturbance patches and topographic diversity through large-scale erosion and deposition of sediments. Against these larger-scale geomorphic features, more frequent, low-power floods produce smaller-scale, spatially complex hydrologic gradients that control patterns of vegetation establishment and successional processes. The presence of water, nutrient-rich soils, and the interspersion of a diversity of successional aquatic and terrestrial biotic communities make bottomland forests, particularly in arid regions, more productive and biologically diverse than surrounding uplands (Brinson 1990; Knutson et al. 1996). Given this, it seems especially relevant to evaluate the importance of floodplain topographic diversity in the design and implementation of this project. These results would be valuable in the design and implementation of future projects aimed at restoring aquatic and riparian biodiversity.

4.2.6 Develop an action plan if undesirable, non-native plant species become established in the Robinson reach.

The objective of active revegetation is typically to restore structural and biological diversity while precluding the establishment of undesirable non-native species. Because of large-scale physical disturbance associated with restoration of the channel and floodplain in the Robinson reach, there is a possibility that undesirable, non-native plant species may become established. Once established, non-native herbs can persist on sites by maintaining non-native seed banks and creating soil and litter conditions that inhibit native species. The Panel was concerned that there did not seem to be a plan to prevent establishment of non-native species.

Active revegetation of riparian shrubs and trees in the western Unites States has often failed due to an insufficient understanding of establishment and survival requirements of native species. Restoration of key physical processes such as flow variability and channel change, in concert with active revegetation, is critical since the displacement of native wetland and riparian vegetation by invasive, non-native species is typically associated with alteration of the natural hydrologic regime and land-use practices that reduce flooding, lower water tables, disturb soils and alter their physical and chemical properties.

To avoid the establishment of undesirable vegetation, species such as smartweeds (*Polygonum* spp.), rice-cut grass (*Leersia oryzoides*), and sod-forming *Carex* species have been suggested as potential native cover crops in the mid-west. Annual cover crops can quickly occupy sites, stabilizing the soil surface and usurping positions that might otherwise be taken by undesirable, but persistent, species. More slowly growing and colonizing native species may gradually replace the annuals over time. Multi-species native seed mixes, as well as planting of individual trees and tree cuttings may mitigate deficiencies in seed source and accelerate the dominance of slowly dispersing species.

In the southwestern United States, attempts to actively restore native riparian understory species by planting, removal of non-natives, and use of commercial soil-amendments were ineffective largely because of the rapid re-growth or establishment of non-native species already occupying a site. Recommendations for minimizing the possibility that undesirable species will take over the floodplain include the following:

- Seeding should be done over several years to accommodate climatic and hydrologic variability,
- Seed mixes should include species reflecting a diversity of life-history traits so species can sort out across the range of fine-scale environmental conditions that may exist at the restoration site, and
- Some weedy native annuals may compete well initially with non-natives.

In addition to active revegetation efforts, natural floods may be the most effective and practical strategy for restoration of native riparian herbaceous communities, as decreases in some non-natives and increases in native species were noted following a 1 in 10 flood event (Wolden and Stromberg 1997).

4.3 MONITORING

One of the fundamental requirements of an adaptive management program is that sufficient data need to be collected before and after project implementation to learn something conclusive. Full-scale projects should not be carried out until scientific and technical evaluation shows that they are feasible and until monitoring methods have been tested to enable a reliable evaluation of project success and ecosystem response. In some cases with the restoration projects on the Merced River this basic conceptual foundation of adaptive management has not been given sufficient attention.

4.3.1 Gather sufficient baseline data on the natural history of chinook salmon and other native species.

There is very good information on adult chinook salmon abundance and distribution and smolt output for the Merced River. However, there appears to be relatively little information on other aspects of the freshwater life history of these fish. Some of the monitoring needs to be dedicated to improved understanding of the life history stages of salmon that are poorly understood and to collecting population and ecological data on some of the other species of interest. As noted elsewhere in this report, the availability of smolt and spawner data for the chinook salmon provides a foundation for studies on egg-fry survival, rearing habitat preferences and growth rate.

The Panel believes it will be critical to the success of restoration on the Merced River (and in other rivers) that better information on abundance, distribution and habitat use by aquatic, terrestrial and avian species be gathered. The Panel was disturbed to find how little information was available on species in the system other than salmon, despite the fact that several of the native fish species have become quite rare. Some information on the distribution of other fish species in the river could be collected coincident with work on salmon rearing habitat. However, as non-salmonid fishes often use habitats different than those used by salmon, investigations at locations not utilized by salmon would need to be conducted to begin developing an understanding of these species. In most cases the Panel believes this can be done in a non-destructive manner. Although it would be nice to have this information prior to initiating restoration, there is no need to delay restoration because this information is lacking. It will be necessary, however, to include areas outside those currently under restoration to provide comparative data on habitat use in restored and un-restored environments. The collection and analysis of such data often provides a good basis for graduate theses, particularly Masters theses so collaboration with universities could be very beneficial here. The same is true for sensitive terrestrial and avian species.

4.3.2 Collect integrated measurements of surface and groundwater.

Lack of sufficient baseline data and development of analytically sound conceptual models will result in any effort at adaptive management becoming simply a trial and error process. Baseline data are a vital component of all projects to identify existing conditions, establish information to use for project design, compare pre-construction and post-construction conditions to measure project performance, and (on the tributary scale) to determine ecosystem response.

It is important that the initial conditions on the Merced River be characterized more thoroughly than has been done to date before the next round of projects is designed and implemented. The development of an integrated understanding of surface and alluvial ground-water dynamics should be given a high priority because a number of important biological responses are linked to these hydrologic site variables, such as salmon spawning runs and vegetation establishment and survival.

Integrated groundwater/surface water measurements could be developed through a network of ground-water wells on the floodplain in combination with stage gages in the river. The stage gages could be either standard staff gages that would be manually read periodically, or pressure transducer-type gages that would provide a continuous recording of the river stage.

Developing a predictive understanding of surface/ground-water dynamics requires consistent measurement over a period of time sufficient to characterize typical seasonal variability. More extreme events, like floods or drought periods, could be measured opportunistically and would be important to record since such events can have long-lasting influence on the abundance and diversity of aquatic and riparian species.

4.3.3 Make a stronger commitment to monitoring.

The restoration team has a vested interest in observing the results of their channel and floodplain restoration projects, and therefore is highly motivated to establish a good monitoring program. The Panel felt, however, that they do not have the time, the financial resources, or the training to design, implement, and analyze the results of a monitoring program of the scope needed for a project of this complexity. This is not a criticism of the restoration team. Their strengths are clearly in project design and implementation, rather than in design and execution of a monitoring program. The plans that they presented to the Panel for monitoring were cursory, hesitant, and unlikely to yield much useful information that might be transferred to other rivers or reaches to gain efficiencies in future restoration projects.

It seems unfair, or at least unrealistic, to expect a design and implementation team to take on responsibility for long-term monitoring and analysis of a restoration project when the personnel are likely to be given a new set of implementation tasks on another project. The Panel did not hear of any person specifically trained for and tasked with developing a monitoring program and analyzing the resulting data. Everyone who spoke of monitoring the project performance already has many other duties, which are likely to become intense just at those critical times (floods, sediment transport events, salmon migrations and spawning, critical periods of high mortality, budget reporting dates, etc.) when intensive, perhaps round-the-clock measurements need to be made. No one had the technical background to design creative analytical strategies that might be necessary, such as sampling fish numbers in the frequency domain rather than the time domain. Both the measurement and the analytical phases of monitoring require specialized training that is simply not available on this and similar projects. The problem was serious with the Tuolumne River projects that the Panel reviewed, but on the Merced River the problem is more obvious and more urgent because of the magnitude and nature of what has already been accomplished.

4.3.4 Improve the linkage between the physical and biological monitoring designs for the projects.

To develop an effective adaptive management approach it is important to identify specific, desired outcomes for the biological attributes of the system that are expected consequences of the physical modifications of the channel and floodplain. This will allow the monitoring of physical and biological elements of the restoration projects to be explicitly linked as well. Although the expected physical responses of the Ratzlaff and Robinson projects (e.g., bed movement initiated at a certain flow) were specific and there were clear monitoring measures, the biological objectives of the projects were expressed only in a qualitative manner and were not linked to specific physical features. Below are two examples of how to improve and integrate the physical and biological monitoring of the Ratzlaff and Robinson projects.

Chinook Salmon

Chinook salmon passage through the reach and increased availability of spawning habitat were stated objectives for the projects but there was no indication of how much of an improvement in either of these parameters would be sufficient to consider the project successful. In addition, the response in terms of changes in habitat for juvenile rearing was not explicitly stated as an objective. The lack of attention given to rearing habitat suggests that this component is not influencing salmon survival or production in the Merced River. However, the Panel was not offered evidence to support this assumption.

To develop specific objectives for chinook salmon, some basic understanding of the status of the fish prior to project implementation is required. A set of objectives related to density of salmon spawning, egg to fry survival, and density and growth rate of rearing juvenile salmon could have been developed if sufficient pre-project information had been available for the Ratzlaff and Robinson projects. Evaluation of the response of spawning salmon to the channel modification may still be possible as pre-project spawner abundance and distribution data are available. If the project is successful at creating suitable spawning habitat, the proportion of the total population of spawning fish in the river that utilize the Robinson reach should increase. However, this response alone will not indicate an overall increase in the productivity of the chinook salmon population for the entire tributary. To answer this larger question, a more comprehensive evaluation of the response of the fish during all phases of their freshwater life history would be required. A set of nested objectives for salmon, from the project (reach) level to the tributary level, coupled with a monitoring scheme that enables progress against these objectives to be assessed, is required to determine the efficacy of the projects being implemented in the lower Merced River.

Riparian Revegetation

A large portion of the reconstructed floodplain in the Robinson reach is not likely to be worked by the river, but the success of active floodplain revegetation, as well as the timing and amount of surface irrigation, will be strongly influenced by depth-to-ground water on the floodplain. Likewise, successful natural recruitment of early successional riparian vegetation on actively accreting point bars will be in large part a function of flow-related deposition of sediments, the timing of peak flows, and the recession rates of those flows. Thus, the monitoring of actively or naturally established vegetation should be integrated with measurements of physical site factors like surface water dynamics and depth to ground water.

Monitoring could be designed as a number of experiments to test explicit hypotheses. For example, hypotheses linking the survival and growth of riparian trees to ground water could be tested by monitoring depth to ground water together with survival/growth of riparian tree plantings, over a range of floodplain elevations from channel edge to upland boundary.

4.3.5 Link the project-level and river-wide monitoring efforts.

The Merced River enjoys the advantage of efficient smolt trapping providing high quality information on smolt production for the tributary. The data on abundance and distribution of spawning salmon also are very good. These two pieces of information can be used as the foundation for more detailed investigations of the freshwater rearing performance of the salmon at the scale of the entire river below Exchequer Dam. Given sufficient time, the spawner and smolt data alone may indicate the cumulative effectiveness of all the restoration projects. If restoration efforts are successful, some improvement in the number of smolts per spawning female, accounting for density-dependent effects on survival, may be apparent after a sufficient amount of data is accumulated.

Augmenting the smolt and spawner data with information on egg survival and the distribution, abundance and survival of juvenile salmon from emergence from the gravel through outmigration may enable more rapid evaluation of the cumulative success of restoration efforts in the Merced River. In addition, data on rearing salmon can be used to evaluate response to individual projects. Data on salmon rearing success also will enable project-level responses to be linked with tributary-level responses. For example, differential tagging of juvenile chinook salmon rearing in different stream reaches and subsequent capture at the smolt trap could be used to evaluate relative survival of fish utilizing different areas of the river or different types of rearing habitat. The relative success of individual projects could be evaluated by comparing the survival rates of fry or pre-smolts rearing in areas where different types of restoration projects have been implemented and in un-restored reaches of the river. Difference in survival or growth among reaches may help identify key mortality factors operating in the river. Information generated by studies of this type will aid in designing future restoration efforts that are likely to have the greatest effect on salmon populations.

Ideally, future projects on the lower Merced River should be selected based on their capacity to contribute to the attainment of river-wide restoration objectives. As noted above, there is a need to improve on the objectives that currently exist. However, even with improved objectives, assessment of the contribution future projects will make towards the objective is currently hampered by a lack of data. The information necessary to evaluate future projects can be obtained by monitoring if steps are taken to ensure that the monitoring design is nested at multiple spatial scales, enabling integration from the project level to the whole tributary.

4.4 OPPORTUNITIES FOR EXPERIMENTS

The Panel felt that a huge opportunity to improve the technology of river restoration will be missed if some of the uncertainties surrounding these large-scale channel and floodplain habitat restoration projects are not investigated. As with the projects on the Tuolumne River, the Panel felt that there were many opportunities for experimentation within the context of the current and proposed projects on the Merced River. The amount of information to be gained from the projects on the Tuolumne and Merced rivers would be greatly increased if the AFRP and CALFED were to take advantage of these opportunities for experiments.

The channel and floodplain restoration projects on the lower Merced River offer many opportunities for passive and active adaptive experimentation at various time and space scales. For example, the overall restoration of the Merced River can only be a passive experiment (there is only one Merced River on which whatever restoration is undertaken happens). However, the Merced is one of several rivers that will be subject to similar extensive restoration. The opportunity exists, therefore, to approach restoration on these rivers as an active experiment. To date, this does not seem to have been part of the planning with the result that the approach to restoration on the Tuolumne and Merced rivers is rather similar.

Although the overall restoration on the Merced River can only be a passive experiment, there is still a lot of opportunity for active experimentation within the various restoration projects (reaches) on the river. The experiments that could be incorporated into restoration fall into two classes: experiments to evaluate technique, and experiments to evaluate restoration. Experiments to evaluate technique are intended to determine the most effective way of accomplishing a particular kind of restoration. For example, river channels are being redesigned to mobilize gravels of a certain size at current two-year return flows. There is uncertainty as to the sizes of gravel that will be mobilized. An experiment could easily be designed to determine rates at which different gravel sizes are mobilized at two-year return flows. Perhaps a more obvious experiment designed to evaluate technique would be one to determine whether irrigation improves survival of cuttings used in riparian planting. There are many other opportunities to experiment with technique during restoration.

Experiments to evaluate restoration are intended to determine the most effective kinds of restoration action. For example, the single thread meandering channel morphology is assumed to provide the best habitat design for salmon production, but this is by no means certain. Other channel designs, including designs involving multiple channels, back channels, and off-channel refugia during high flows are possible. The restoration efforts on the Merced River offer many opportunities to test different channel designs.

In the Panel's discussions about factors limiting salmonids in both the Merced and the Tuolumne rivers, it was not possible to determine the relative importance of spawning and nursery habitat to improving production. Indeed, there was considerable uncertainty as to whether it was better to encourage fry to remain in the tributaries or to encourage them to move downstream as quickly as possible. The most solid observation on survival seems to be a positive relationship between stream flow and survival. At present there is little information to show how flow effects survival. Such broad uncertainty is most efficiently addressed using experiments. Experiments could be designed to determine how juveniles respond to variations in flow and how stream attributes encourage or discourage residency under different flows. And just as the best kinds of restoration actions to improve salmon production are uncertain so are the best kinds of riparian revegetation to encourage native species. In the Panel's view there are even more opportunities for manipulative experiments on the floodplain than in the river channel.

An Example

The Panel felt that it would be useful to sketch in moderate detail an example of an adaptive experiment that might be conducted in the Robinson Project reach to address uncertainty associated with restoration of fish habitat. The purpose of this example is not to specify what should be done but rather to demonstrate the process for designing an adaptive experiment within the context of an existing restoration project.

The habitat objectives for the Robinson Project are rather general: to increase the quantity and quality of spawning and rearing habitat for chinook salmon. Given that the reach was characterized by sheet flow through shallow ponds prior to restoration and that restoration has created a single thread meandering channel with pools and riffles, it is apparent that the general objective has been met. However, the projected cost of this restoration is also more than $9 million (not all related to fish habitat), so it seemed to the Panel that a clearer specification of habitat objectives for this reach would have been desirable.

The first rule of adaptive management is "specify clear and quantifiable objectives." For example, a more clearly specified objective for spawning habitat would be:

- Through creation of riffles, gravel augmentation and flow management ensure provision of sufficient high quality spawning area to accommodate a minimum of 300 pairs of chinook salmon on a continuing basis.

Uncertainties associated with this objective include such things as:

- What characteristics identify high quality spawning area? Is gravel composition a sufficient measure or are other characteristics also necessary, such as minimum sub-gravel flow, groundwater discharge, etc?

- How frequently and to what extent does the bed material have to be mobilized to maintain quality of spawning beds over time?

- How important is the addition of new gravel to maintaining quality of spawning riffles?

This is by no means a complete list of uncertainties and any experienced fishery biologist could add to this list. Furthermore, biologists are likely to differ in their perception of the relative importance of these and other uncertainties. Such differences of opinion simply testify to the uncertainty about spawning gravel, however, and the above examples will suffice for the purpose of this example.

Each uncertainty suggests the possibility of an experiment to improve the understanding of how to provide and maintain high quality spawning gravel. Because the flows are so well controlled in this river, more kinds of experiments can be contemplated than in a river with a natural, uncontrolled flow regime.

Regarding the first uncertainty above, evidence from other studies suggests that gravel composition alone is not a sufficient criterion of quality of spawning habitat and that sub-gravel flows and/or groundwater inflows may also be important. So the hypothesis would be that spawning area quality is a function of both gravel composition and sub-gravel flows. More specifically, the hypothesis could be that gravel quality is negatively related to the percent of substrate that passes a 1 mm sieve but is positively related to the rate of sub-gravel water flow in mm/hr. This model could actually be parameterized using information from the literature.

With this model in hand one could conduct two kinds of experiments in spawning riffles in the Robinson Reach. The simplest would be to map the quality of spawning gravels in the riffles and predict where the fish should spawn. A more ambitious experiment would be to manipulate sub-gravel flow. For example, one could moor partially submerged logs above the gravel in parts of the riffle to force more water flow through the gravel. By distributing these devices in relation to gravel composition one could more fully test the prediction that chinook choose spawning locations in relation to gravel composition and sub-gravel flows.

Proper implementation and monitoring of such experiments would have a number of benefits. First, the quality of spawning habitats constructed in the Robinson Reach could be evaluated objectively in terms of choice behavior of the fish. Second, future projects would benefit from knowing the relative importance of gravel composition and sub-gravel flows. Third, a predictive spawning habitat quality model would be tested and its parameters specified and this could be used in other restoration projects. An additional "spin-off" benefit of such experiments might be a method to attract fish to spawn in certain locations where further investigation (of egg or fry survival, for example) could be performed.

In a similar manner, experiments could be envisioned and designed to address the additional uncertainties listed above and uncertainties associated with other objectives. The restoration effort on the Merced River provides many excellent opportunities to conduct experiments like the example above. Which experiments should be pursued to provide the best information depends on the specification of the overall conceptual model for restoration on the river and the integration of the individual reach projects.

4.4.1 Gather water quality data and investigate potential non-lethal effects of various contaminants on the fish.

An aspect of salmon habitat that seems to be largely ignored in the restoration planning for the Merced River (and Tuolumne River also) is the potential role chemical contamination may have on the capacity of certain reaches to support juvenile salmon. Direct mortality of salmon as a result of exposure to pesticides or industrial chemicals likely will be a rare. However, recent work with certain classes of chemicals, including organo-phosphate and carbamate insecticides, indicates inhibition of certain aspects of neurological function in salmonids at very low concentrations; two to three orders of magnitude lower than that required for direct mortality (Scholz et al. 2000). These nervous system alterations can affect salmon behavior in ways that may impact survival. For example, concentrations of diazinon as low as 1.0 ug/l have been shown to cause a significant loss in olfactory capacity, rendering juvenile salmon much less able to detect predatory fishes. Concentrations of 10.0 ug/l impair homing ability of adult salmon. A survey of diazinon concentrations in streams in the San Joaquin Valley found concentrations over 0.1 ug/l at 71% of the sites evaluated (Dubrovsky et al. 1998), indicating that these chemicals are present.

There is little that can be done as part of the restoration program on the Merced River to alter the concentration of chemical contaminants. However, some understanding of the distribution and concentration of these chemicals in the system may be useful in prioritizing restoration efforts and in designing experiments to better understand their effect. For example, the hypothesis that projects designed to reduce predator abundance may have a greater impact on survival if implemented in areas where risk of exposure to chemical contamination exists could be tested by monitoring juvenile salmon survival at projects to reduce predator abundance in areas with different concentrations of contaminants. An alternative hypothesis might be that projects designed to increase the quality or quantity of rearing habitat are most effective in locations where the risk of chemical exposure is low and fish attracted to the improved habitat would not have reduced capacity to avoid predators.

4.4.2 Conduct low flow investigations.

Discharge and the abundance of spawning chinook salmon appear to be related in the Merced River. Following the 1968 closure of New Exchequer Dam, increases in the number of returning salmon occur during periods with higher than average annual peak flows and declines in adult salmon abundance correspond with one to several years of low annual peak flows. This same pattern was noted in the Tuolumne River Forum Report, suggesting that salmon survival is closely linked to flow patterns in these river systems. The restoration team clearly recognizes the importance of flow on salmon survival. However, this understanding is not reflected in the process used to identify restoration projects or in the monitoring plans.

This relationship with flow suggests that the key mortality factors impacting chinook salmon in the Merced River may operate most intensely during periods of low flow. As a result, the identification of the primary factors limiting salmon survival may be achieved most efficiently if focused investigations of salmon population performance occur during episodes of low-flow. Measurements might include a more comprehensive assessment of egg to fry survival, extensive sampling of the distribution of rearing fry, and data on the growth, condition factor or other attributes that relate to survival. The improved understanding of the factors responsible for poor performance of the salmon during dry periods can help to identify restoration activities most likely to improve salmon survival and provide a basis for developing a monitoring strategy that includes those variables of greatest significance to the fish.

4.4.3 Conduct experiments with the revegetation design.

To improve the success of the riparian revegetation and increase our understanding of riparian plant ecology, the revegetation experiments recommended by Dr. Julie Stromberg for the Tuolumne River could be incorporated into the revegetation plans for the Merced River. The restoration team is referred to section 4.4.2 of the Tuolumne River Adaptive Management Forum Report (http://www.delta.dfg.ca.gov/afrp/afrp.asp Tuolumne River Watershed) for a detailed description of the experiments. The experiments selected will need to coincide with specific restoration objectives for the Merced River, in particular the objectives for the floodplain restoration projects.

4.4.4 Design experiments related to channel complexity.

A hypothesis related to channel design that could be tested might be: will simple channel designs will evolve to the desired level of complexity in a reasonable time frame without jeopardizing stability of the project?

A set of experiments could be developed to test this hypothesis by constructing different reaches to different levels of complexity, and monitoring those reaches over time to determine which point in the continuum from very complex to very simple designs provides the best chance for project success. The hypothesis is obviously very broad, and would need to be broken down into simpler pieces and expressed in quantitative terms so that an appropriate experimental design could be implemented.

Specific attributes that could be monitored to test this hypothesis include changes in cross sectional shape with time in bends and crossings, changes in the thalweg profile with time associated with the cross sectional changes, and rates of bank erosion in areas where lateral migration occurs. A primary objective of measuring these attributes would be to determine whether or not simple channel shapes will evolve into the more complex shapes found in natural channels in an acceptable period of time after construction of the restoration project.

A likely outcome of the experiments is that a simple design works well for some elements and a more complex design is required for other elements.

The designs for the Merced River projects appeared to be supported by a much higher level of quantification than those on the Tuolumne River. But the uncertainties at this step in the process provide many excellent opportunities for experimentation in the context of adaptive management.

4.4.5 Establish an investigation team to design, conduct, and analyze scientific research on the Merced River.

The current restoration projects on the Merced River have created a strong set of hypotheses, which if thoroughly evaluated, could provide much useful information for both the future restoration and management of the Merced River and for restoration projects on other large gravel-bedded rivers. These hypotheses involve such things as future channel adjustments in size and position and the ability to predict them; the frequency and degree of channel bed scour and self-cleansing; and the frequency, sediment distribution, and vegetation-disrupting power of overbank flows, etc. The Merced River provides a unique opportunity to learn about what works in river restoration. Unless specific actions to capitalize on this opportunity are taken, however, the Panel believes the opportunity will be lost.

This is a unique opportunity for river restoration team members, federal and state agency program staff and managers, public policy makers, and the public to learn about what works in river restoration and it deserves to be adequately addressed.

Some group, not already burdened by other responsibilities, and having skills in experimental design, monitoring, and analysis needs to be assigned the task of designing and conducting a scientific investigation of the world-class laboratory that has been created by the existing and proposed channel and floodplain restoration projects on the lower Merced River. The Panel knows of no better opportunity in the world for obtaining transferable, high-quality data on the restoration of a river.

There is some urgency in setting up such a study team because although there was limited pre-project monitoring, the first changes resulting from the next set of high flows will reveal much about how rivers designed according to this distinctive and well-specified conceptual model respond to actual flow events, fluctuations of riparian ground water levels, weather events, and biological perturbations. Contingency is an important influence on the early phases of restoration (and perhaps the later phases also), so there is much to be gained from early deployment of a monitoring scheme that is robust, effective, and analyzable.

Accomplishing this goal will require an early and strongly funded commitment by the AFRP and CALFED and other relevant agencies to recruit and fund a team with the necessary range of skills.

4.5 COORDINATION OF PROJECTS AND EXPERIMENTS (DESIGN, IMPLEMENTATION AND MONITORING) ON THE MERCED AND TUOLUMNE RIVERS

Both the Merced and Tuolumne rivers are being subjected to large scale and expensive programs of ecosystem restoration involving reconstructing river channels and floodplains, re-vegetating floodplains, and filling mid-channel pits or rerouting river channels around mining pits. Given the size and cost of these projects and the similarity in approach, close cooperation and coordination would obviously pay high dividends. Because the restoration teams for the two rivers share a few members there is some communication between the two; but there is no structured or facilitated coordination. There are many ways that the projects could benefit from each other in ways that would enhance restoration and save money in the long term. Two such opportunities are discussed below.

4.5.1 Share chinook salmon life-history information.

There is a clear need for additional life history information for chinook salmon for both the Merced and Tuolumne rivers. The Panel found that information on factors such as the utilization of freshwater habitat during rearing and the temporal and spatial distribution of key mortality factors was lacking. This type of information is critical to identifying the projects with the greatest potential to benefit salmon and designing a monitoring program that efficiently assesses project effectiveness. Much of the biological information required to address the current deficiencies in knowledge is very expensive and labor intensive to obtain. Therefore, coordinating efforts to collect this type of information on the two rivers would be beneficial to both restoration efforts.

Although project-specific information will often be relevant only to the location of that project, general information on habitat preferences of juvenile salmon, key mortality factors at different life history stages and other information relating to the general behavior of the fish should be comparable between the two tributaries. The similarity in the relationship between abundance of returning adult salmon and river flow suggests that there are strong similarities in the way the salmon are using habitat and responding to environmental factors in the Merced and Tuolumne rivers. By coordinating and collaborating on data collection and analysis efforts for these two rivers our understanding of the ecology of chinook salmon could be greatly improved in an efficient way.

4.5.2 Share vegetation information and compare revegetation plans.

Although it was mentioned that Jeff Hart’s vegetation work on the Tuolumne River was used in the revegetation design work on the Merced River, the Panel felt that there could be more coordination and cooperation, especially with regard to experimentation, between the revegetation design teams on the two rivers.

As with salmon, sharing of revegetation design plans, along with the results of subsequent monitoring of key physical and biological variables can help to refine the design and implementation of both passive and active revegetation efforts. For example, survival and growth of planted woody riparian vegetation on created floodplain surfaces will be strongly dependent on underlying water-table dynamics. The monitoring of survival, and growth of these established plants in relation to water-table depth, across a number of sites, could help to define a range of elevations at which a particular species would be expected to survive and grow.

5. REFERENCES CITED

Brinson, M. M. 1990. Riverine forests. Pages 87-141 in A. E. Lugo, M. M. Brinson, and S. Brown, editors. Forested wetlands. Elsevier, Amsterdam.

CALFED, 2001. Ecosystem Restoration Program, Draft Stage 1 Implementation Plan, Chapter 2.0. August 2001. http://calfed.ca.gov/adobe_pdf/ecosystem_docs/DraftStage1ImplementationPlan.pdf

Dubrovsky, N. M., C. R. Krazner, L. R. Brown, J. M. Gronberg and K. R. Burow. 1998. Water quality in the San Joaquin – Tulare basins, California, 1992-1995. U.S. Geol. Surv. Circ. 1159.

FISRWG (10/1998). Stream Corridor Restoration: Principles, Processes, and Practices. By the Federal Interagency Stream Restoration Working Group (FISRWG - 15 federal agencies of the US government). GPO Item No. 0120-A; SuDocs No. A 57.6/2:EN 3/PT.653. ISBN-0-934213-59-3.

Knutson, M. G., J. P. Hoover, and E. E. Klaas. 1996. The importance of floodplain forests in the conservation and management of neotropical migratory birds in the Midwest. Pages 168-188 in F. R. Thompson, editor. Management of mid-western landscapes for the conservation of neotrpical migratory birds. General technical report NC-187. U.S. Forest Service.

Scholz, N. L., N. K. Truelove, B. L. French, B. A. Berejikian, T. P. Quinn, E. Cassilas and T. K. Collier. 2000. Diazinon disrupts antipredator and homing behaviors in chinook salmon (*Oncorhynchus tshawytscha*). Can. J. Fish. Aquat. Sci. 57: 1911-1918.

Walters, C. 1986. Adaptive management of renewable resources. MacMillan, New York, NY.

Wilcock, P., 1997. Friction between Science and Practice: The Case of River Restoration. American Geophysical Union, EOS, v.78, October.

Wolden L. G., and J. C. Stromberg. 1997. Experimental treatments (and unplanned natural events) for restoration of the herbaceous understory in an arid-region riparian ecosystem. Restoration & Management Notes 15:161-167.